Aerodynamic Measurements of an Incidence Tolerant Blade in a Transonic Turbine Cascade

Ashlie B. McVetta
NASA Glenn Research Center, Cleveland, Ohio

Paul W. Giel
ASRC Aerospace, Cleveland, Ohio

An overview of the recent facility modifications to NASA's Transonic Turbine Blade Cascade Facility and aerodynamic measurements on the VSPT incidence-tolerant blade are presented. This work supports the development of variable-speed power turbine (VSPT) speed-change technology for the NASA Large Civil Tilt Rotor (LCTR) vehicle. In order to maintain acceptable main rotor propulsive efficiency, the VSPT operates over a nearly 50% speed range from takeoff to altitude cruise. This results in 50° or more variations in VSPT blade incidence angles.

The Transonic Turbine Blade Cascade Facility has the ability to operate over a wide range of Reynolds numbers and Mach numbers, but had to be modified in order to accommodate the negative incidence angle variation required by the LCTR VSPT operation. Details of the modifications are described.

An incidence-tolerant blade was developed under an RTPAS study contract and tested in the cascade to look at the effects of large incidence angle and Reynolds number variations. Recent test results are presented which include midspan exit total pressure and flow angle measurements obtained at three inlet angles representing the cruise, take-off, and maximum incidence flight mission points. For each inlet angle, data were obtained at five flow conditions with exit Reynolds numbers varying from 2.12×10^6 to 2.12×10^5 and two isentropic exit Mach numbers of 0.72 and 0.35. Three-dimensional flowfield measurements were also acquired at the cruise and take-off points. The flowfield measurements were acquired using a five-hole and three-hole pneumatic probe located in a survey plane 8.6% axial chord downstream of the blade trailing edge plane and covering three blade passages. Blade and endwall static pressure distributions were also acquired for each flow condition.

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

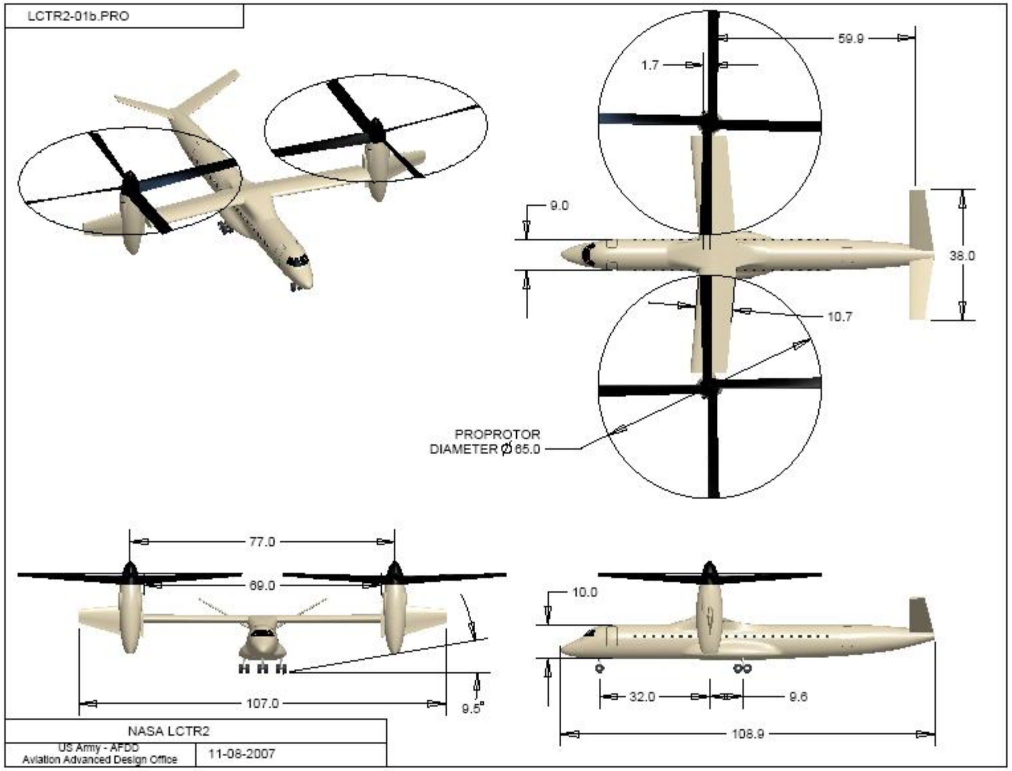
Aerodynamic Measurements of an Incidence Tolerant Blade in a Transonic Turbine Cascade

Ashlie McVetta
Aerospace Engineer
RTT/ NASA Glenn Research Center

Dr. Paul W. Giel
ASRC Aerospace
RTT/NASA Glenn Research Center

2012 FAP Technical Conference
March 13-15, 2012

Motivation for VSPT Technology



Large Civil Tilt-Rotor	
TOGW	108k lbm
Payload	90 PAX
Engines	4 x 7500 SHP
Range	> 1,000 nm
Cruise speed	> 300 kn
Cruise altitude	28 – 30 kft

Principal Challenge

Variability in main-rotor speed:

– 650 ft/s VTOL

– 350 ft/s at Mn 0.5 cruise

≈10 pts. in η_{prop}

Approaches

– Variable gear-ratio transmission

– Variable-speed power turbine **(VSPT)**

VSPT Challenges

– Wide incidence variation

– Transitional Reynolds numbers

VSPT Approach

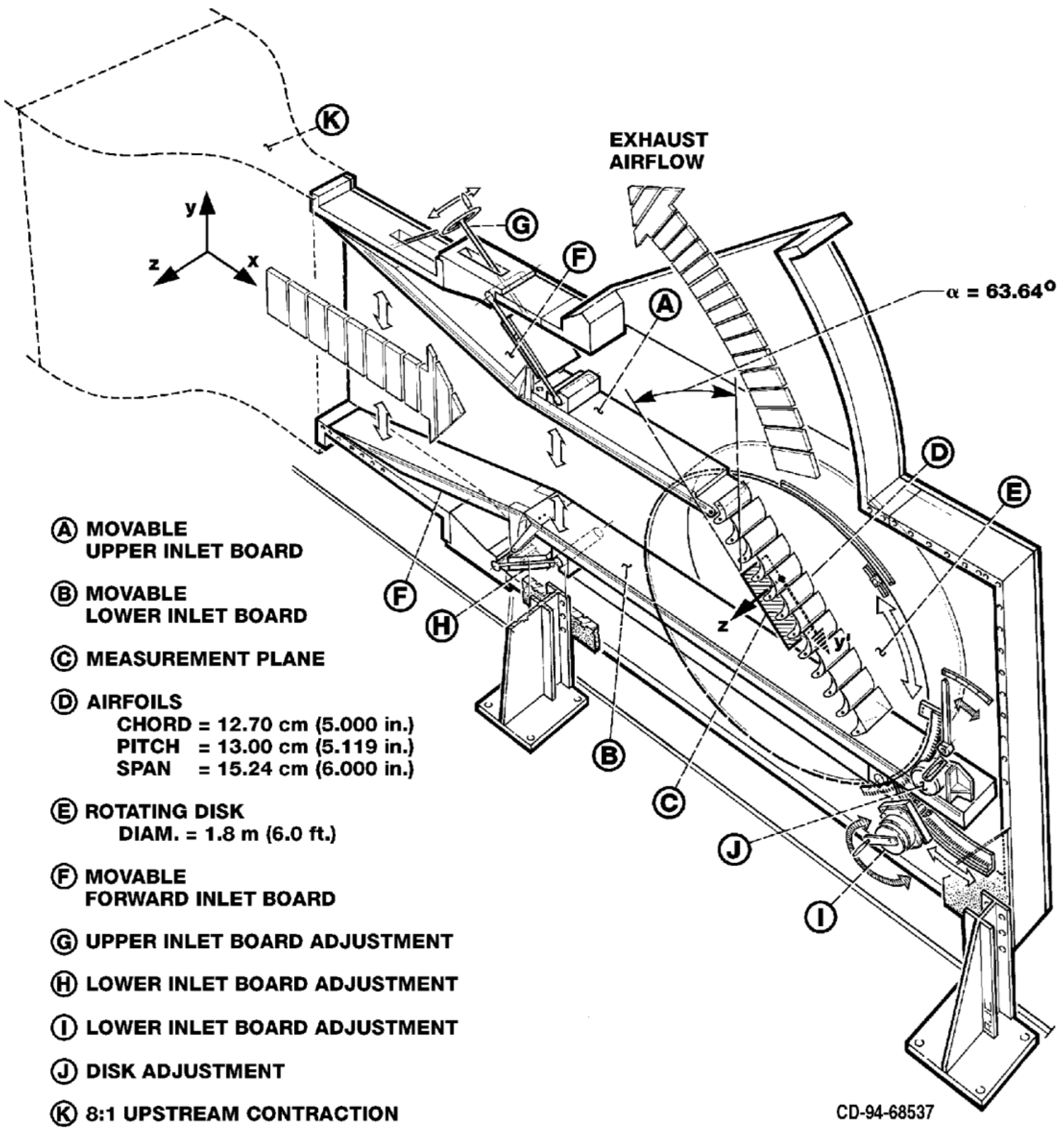
– Incidence tolerant blade

– Reynolds number variation

– Detailed measurements for CFD code/model validation needed.

Acree, Hyeonsoo, and Sinsay, Int. Powered Lift Conf., 2008.

Transonic Turbine Blade Cascade



Ⓐ MOVABLE UPPER INLET BOARD
Ⓑ MOVABLE LOWER INLET BOARD
Ⓒ MEASUREMENT PLANE
Ⓓ AIRFOILS
CHORD = 12.70 cm (5.000 in.)
PITCH = 13.00 cm (5.119 in.)
SPAN = 15.24 cm (6.000 in.)
Ⓔ ROTATING DISK
DIAM. = 1.8 m (6.0 ft.)
Ⓕ MOVABLE FORWARD INLET BOARD
Ⓖ UPPER INLET BOARD ADJUSTMENT
Ⓗ LOWER INLET BOARD ADJUSTMENT
Ⓘ LOWER INLET BOARD ADJUSTMENT
Ⓙ DISK ADJUSTMENT
Ⓚ 8:1 UPSTREAM CONTRACTION

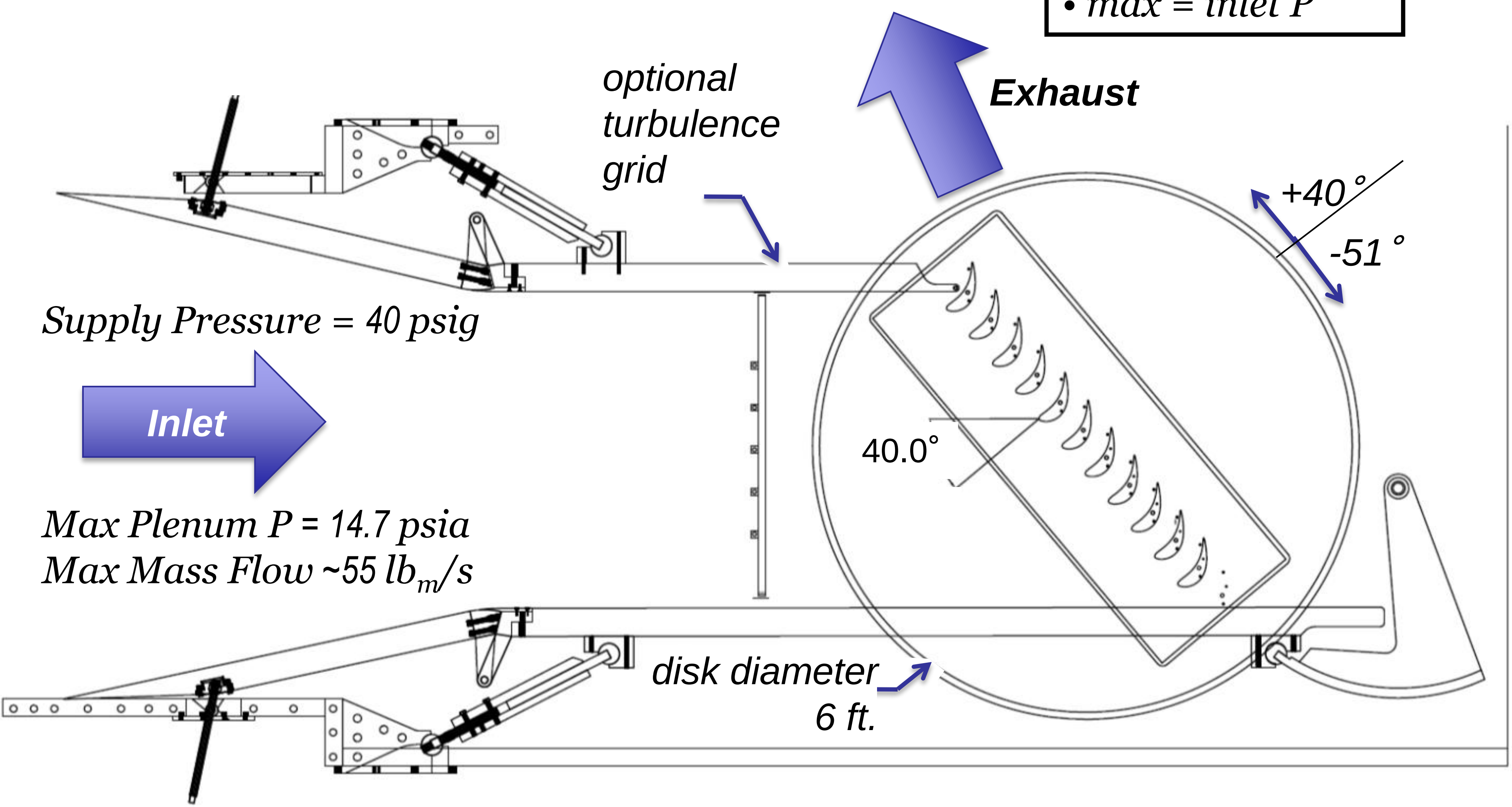
Blades:
- 11 blade passages
- span = 6.000″ (fixed)
- pitch = 5.119″ (fixed)
- axial chord ~5″ (typical)

Inlet:
- dry, clean, ambient *T* (filtering: 98% of 0.35μm 99.9% of 2 μm)
- well-documented inlet; nominal $\delta_{in} \approx$ 1.0 inch
- various static and blown turbulence generating grids available.

Transonic Turbine Blade Cascade Facility

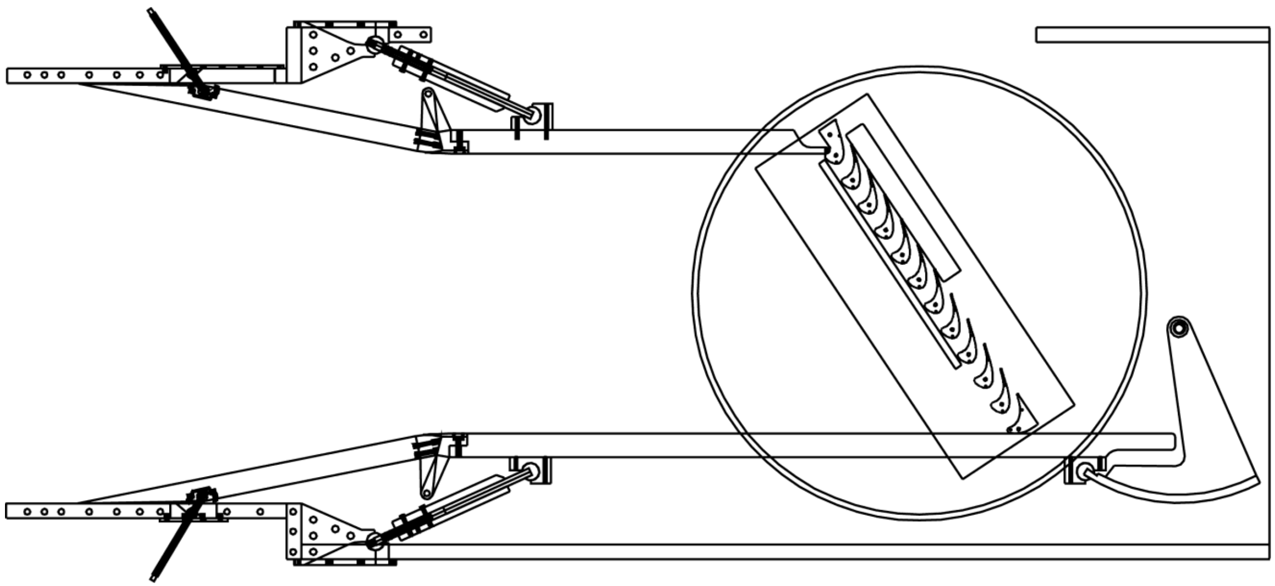
Current Facility Configuration with VSPT incidence-tolerant blade set at the baseline 40.0° inlet angle

Exhaust pressure:
- *min P ≈ 2 psia*
- *max = inlet P*

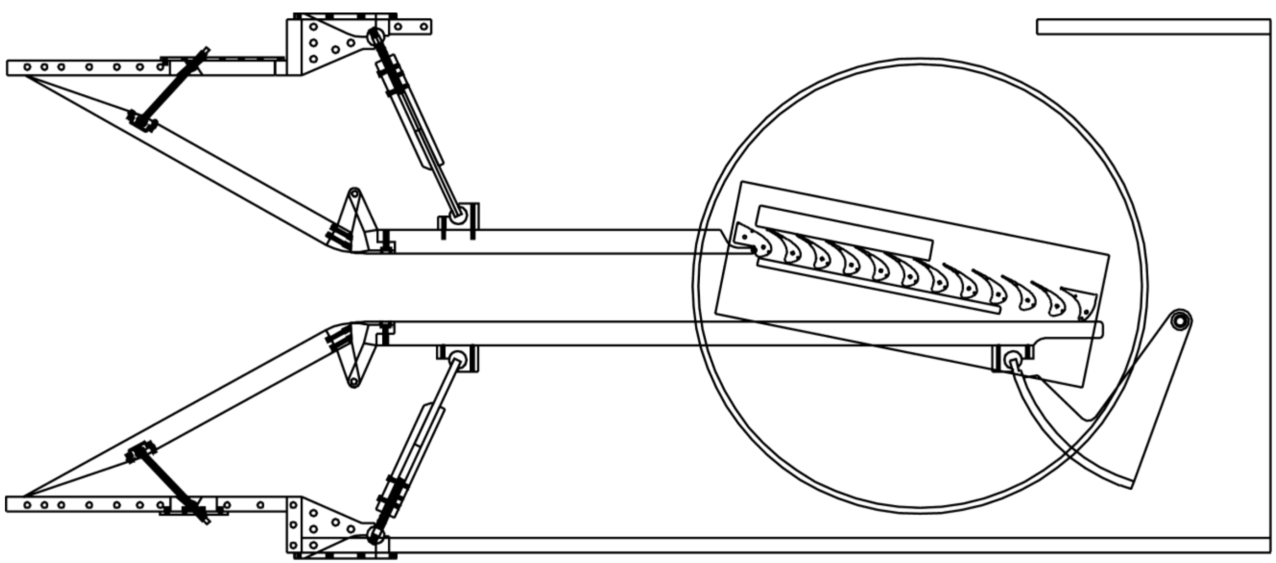


Original Facility at min & max incidence angles

minimum inlet flow angle = 33.8° from axial

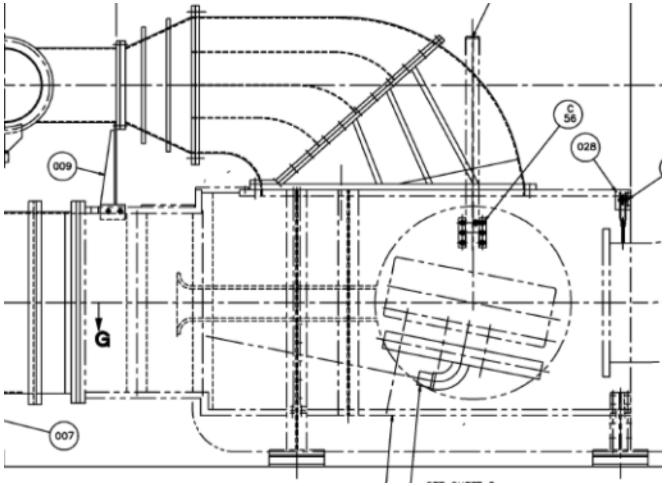


maximum inlet flow angle = 78.6° from axial

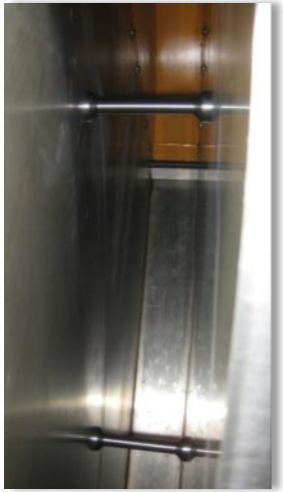


Facility Modifications

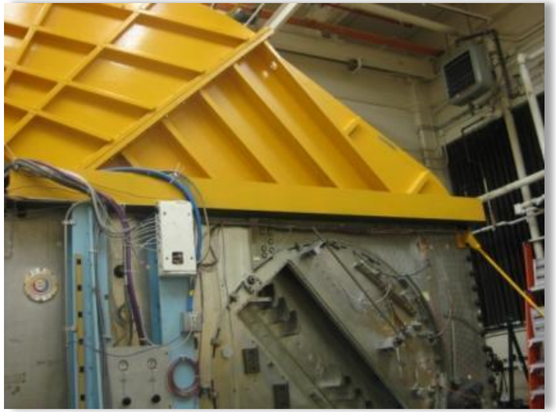
- Extended exhaust duct
- New support bars
- Discrete upper board extensions



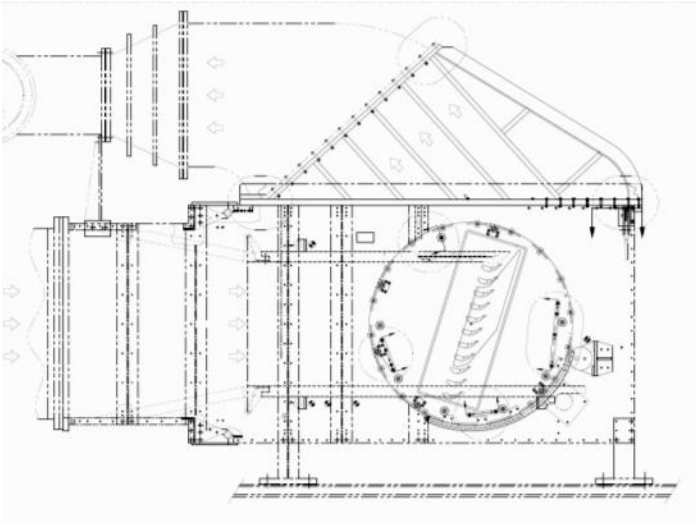
CW-22 Before Modifications



New Support Bars

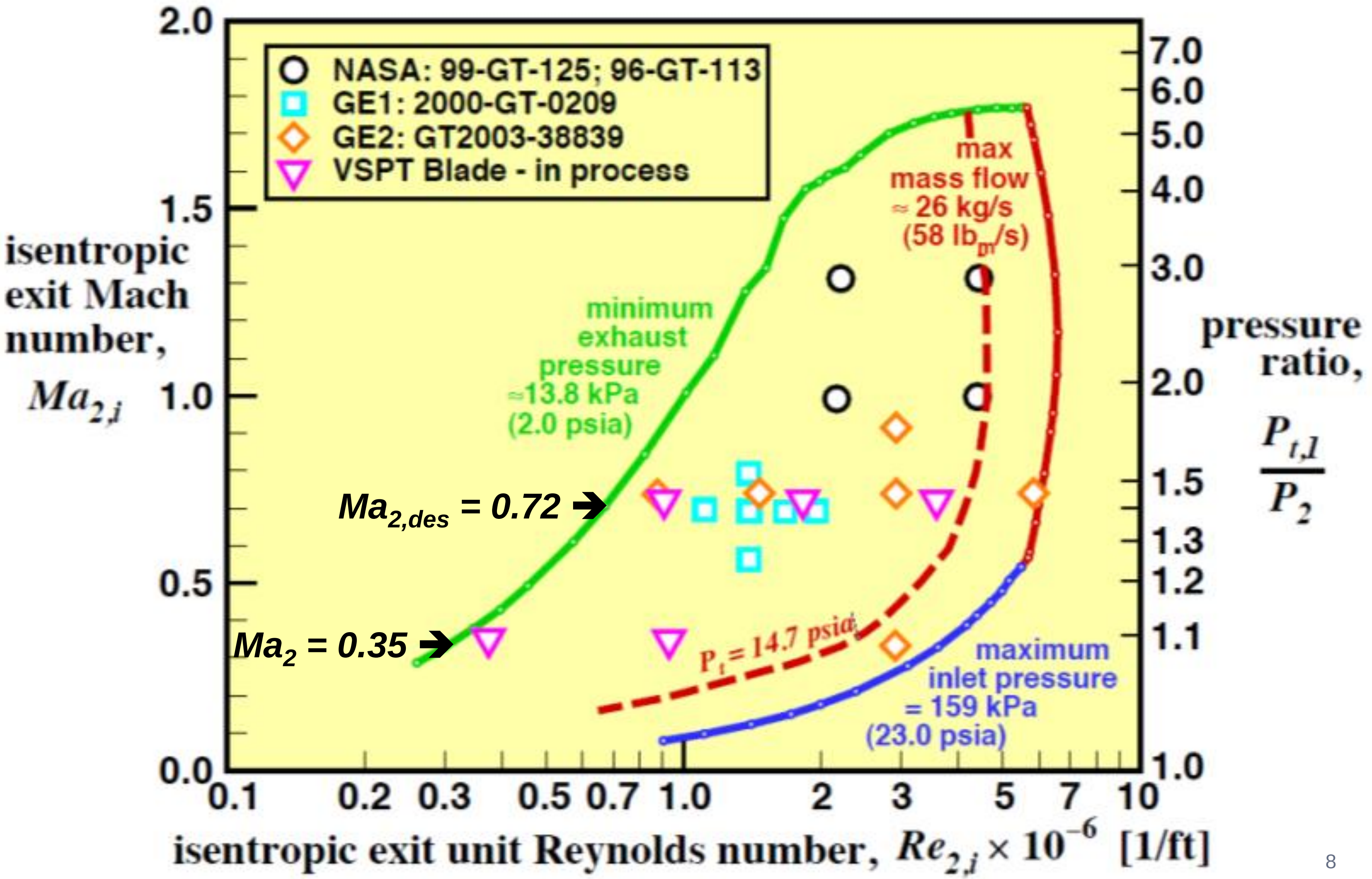


New Exhaust Section

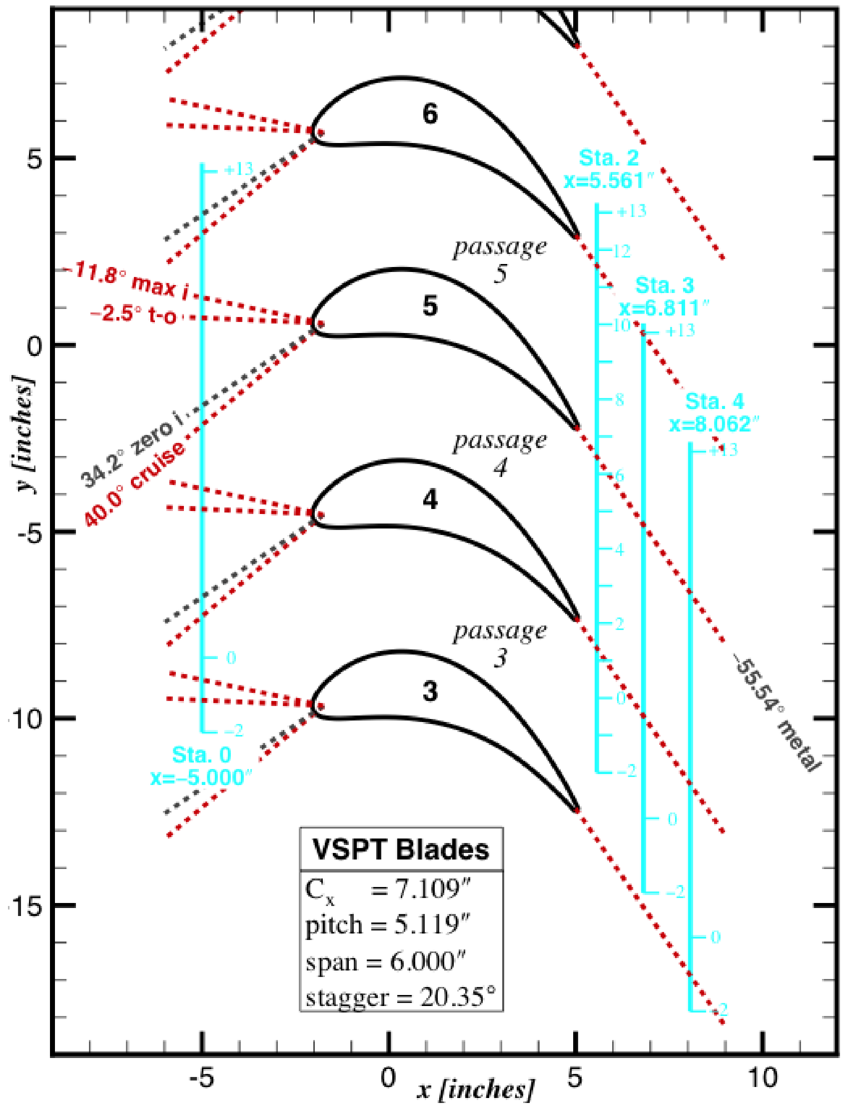


CW-22 After Modifications

Facility Operating Envelope

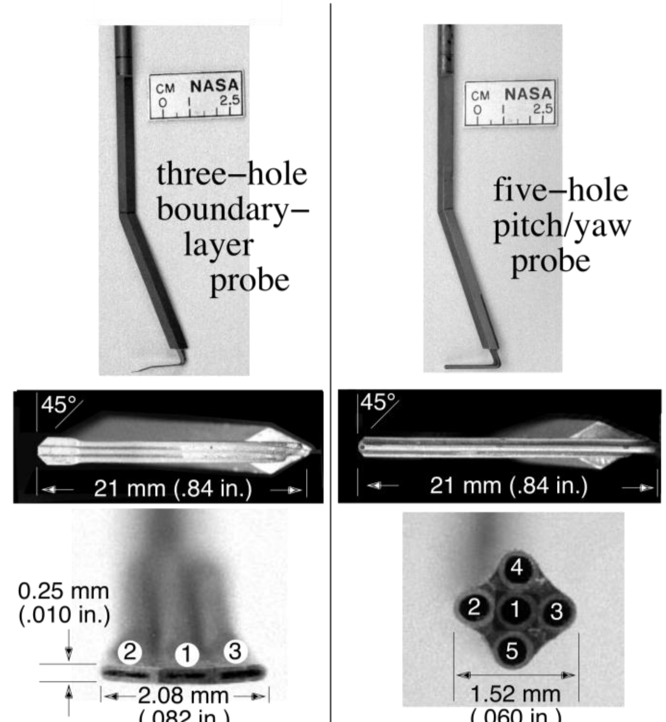


VSPT Aerodynamic Measurements



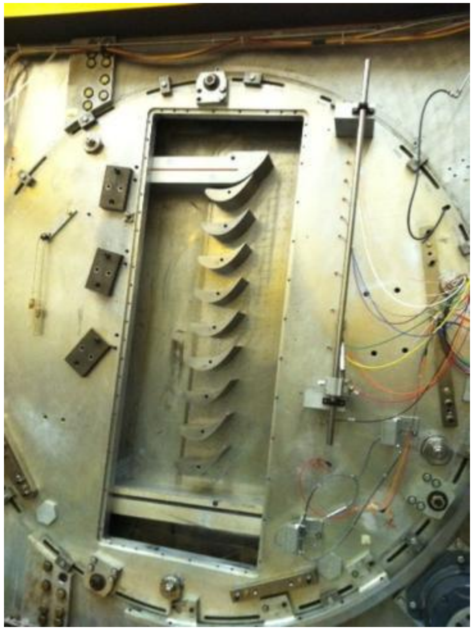
Blade and Survey Planes

- Inlet flow angles: +40.0º, -2.5º, -11.8º.
- 5 flow conditions each.
- 5-hole and 3-hole pneumatic probes.
- Total pressure and flow angles measured 7.0% C_x downstream of trailing edge.
- Blade and endwall static pressure measurements.

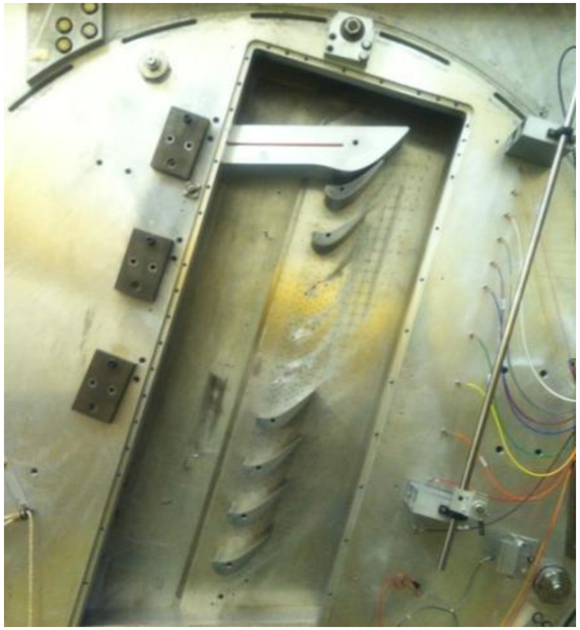


CW-22 Test Configurations

40.0° Inlet Angle
(i = +5.8° Cruise)



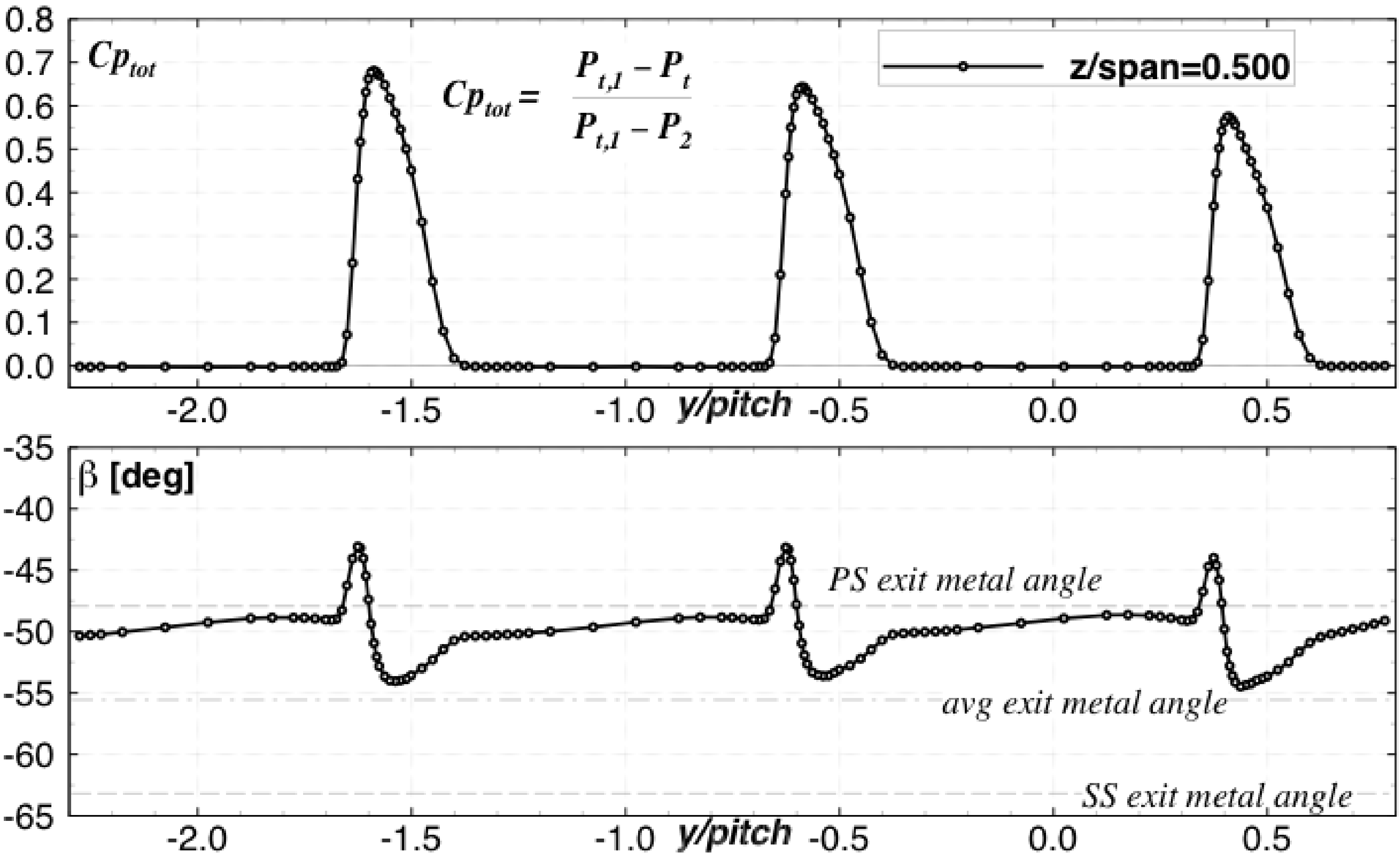
-2.5° Inlet Angle
(i = -36.7° Take-Off)



-11.8° Inlet Angle
(i = -46.0° Maximum Incidence Condition)

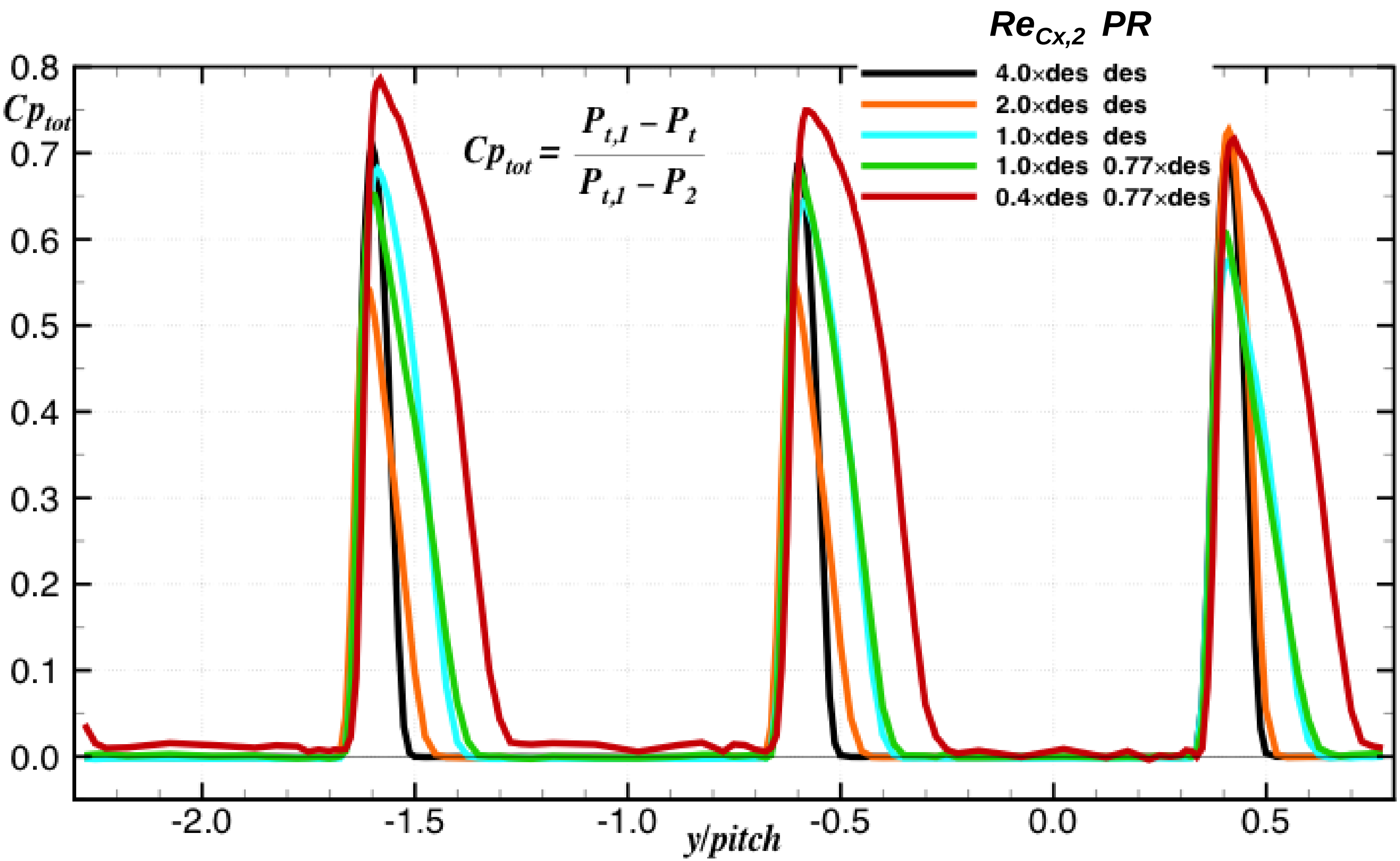
Midspan Probe Loss & Angle Measurements

$Re_{Cx,2}$ = 530,000 (baseline) Ma_2 = 0.72 (PR des)
β_1 = 40.0° (Cruise) i = + 5.8°



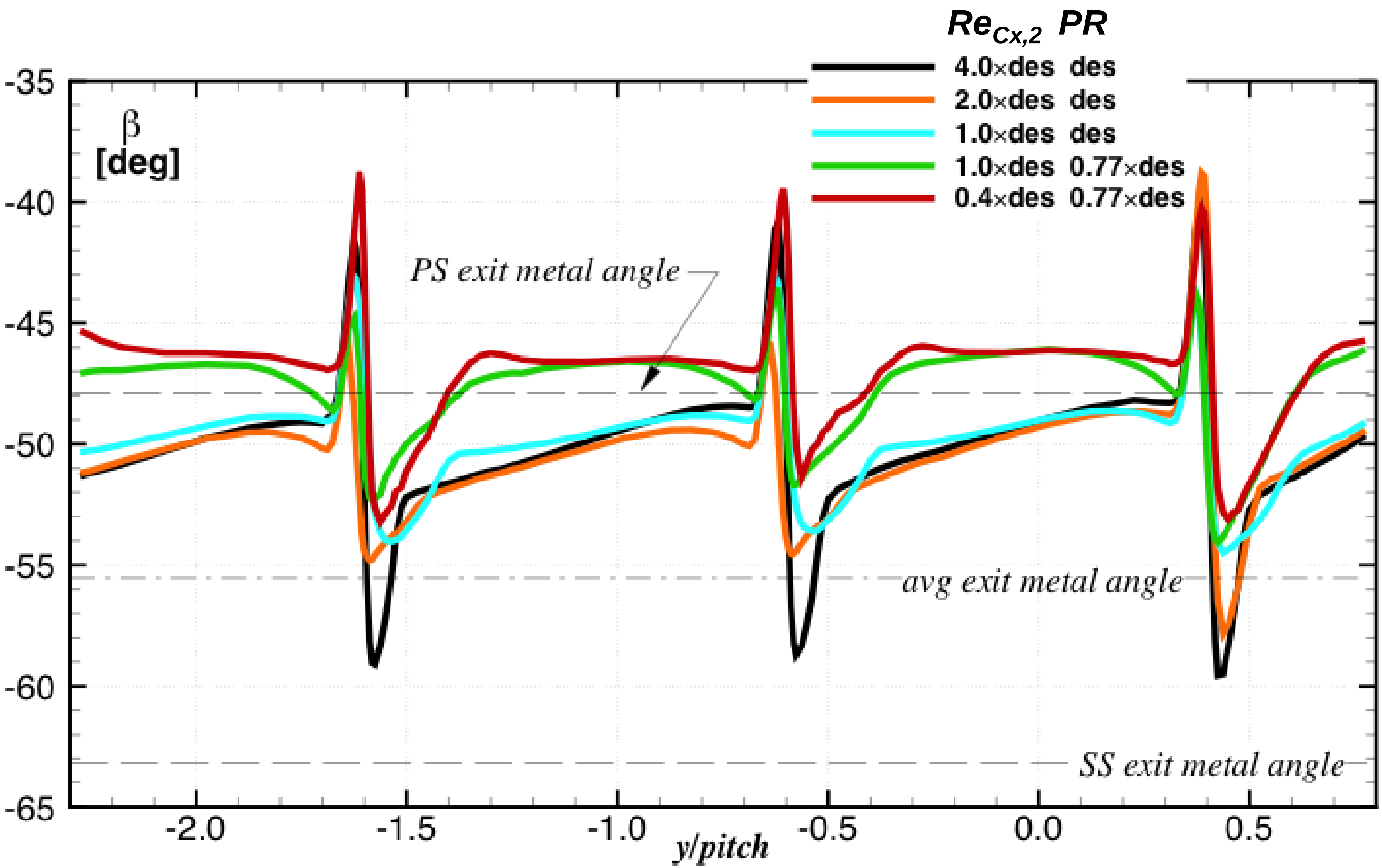
Midspan Probe Loss Measurements

Effects of Reynolds Number and Pressure Ratio at β_1=40.0º (Cruise) i=+5.8º



Midspan Probe Flow Angle Measurements

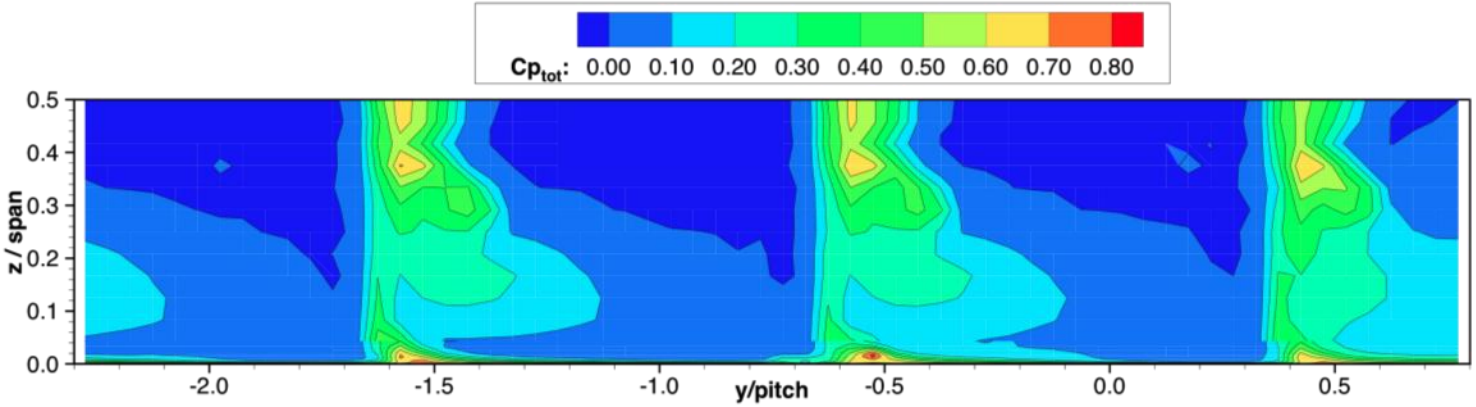
Effects of Reynolds Number and Pressure Ratio on Flow Angle at
$\beta_1 = 40.0^\circ$ (Cruise) i=+5.8º



3-D Flowfield Measurements

$Re_{Cx,2}$ = 530,000 (design) Ma_2 = 0.72 (design) β_1 = 40.0º (Take-Off) i=+5.8º

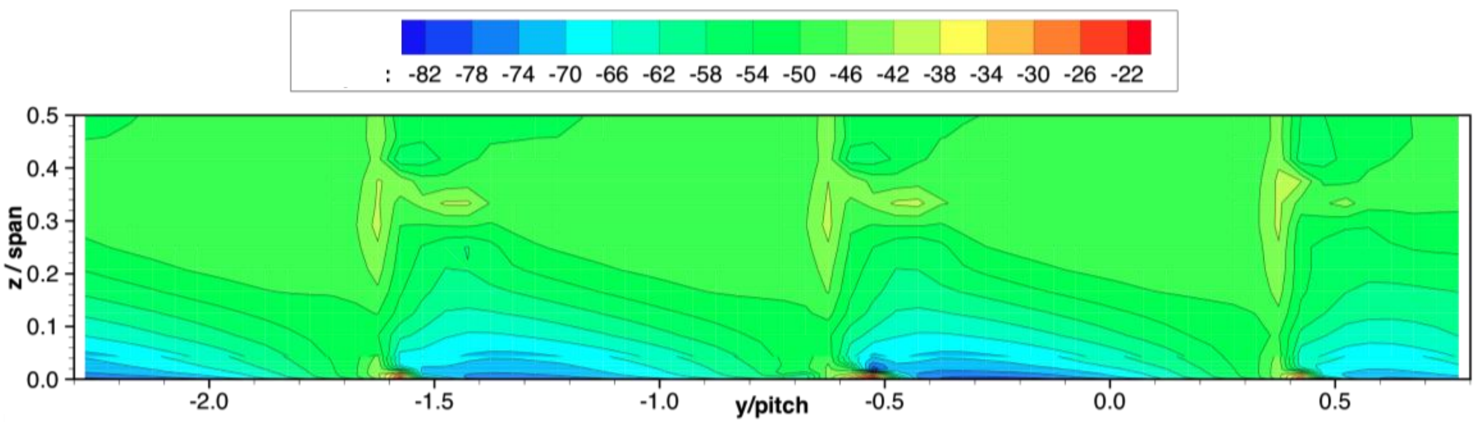
total pressure coefficient



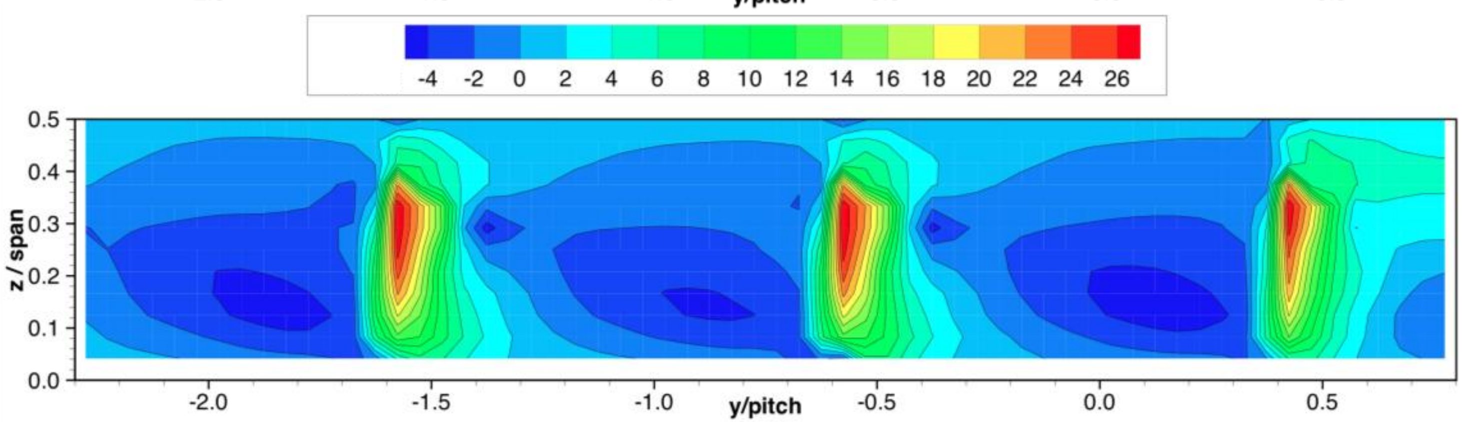
5-hole probe

3-hole probe

pitch flow angle

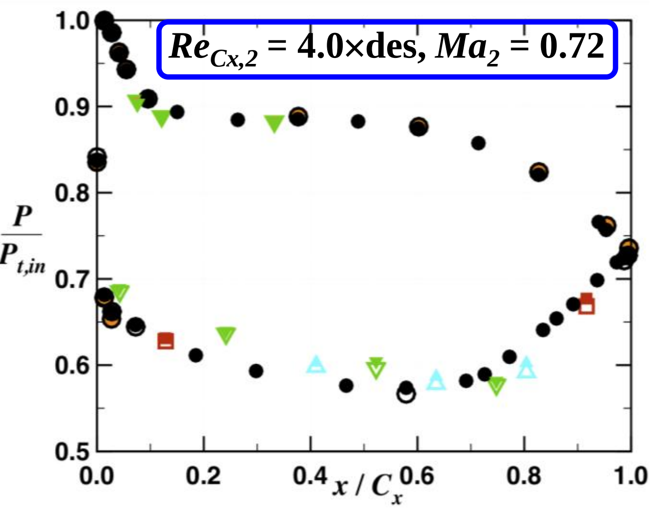


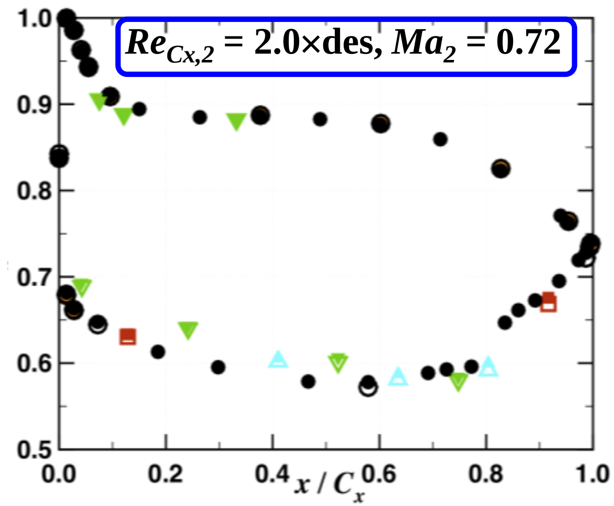
yaw flow angle

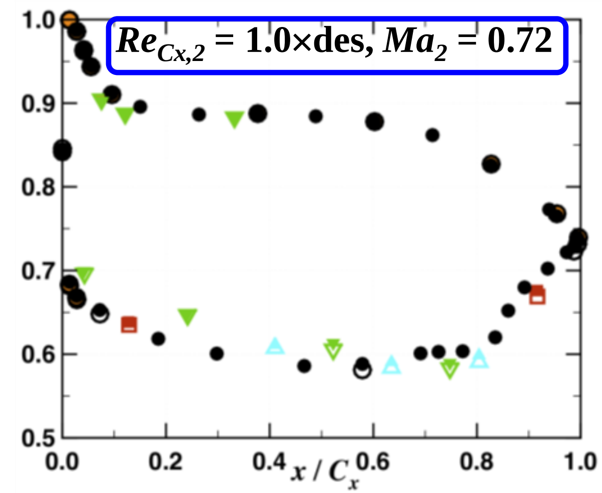


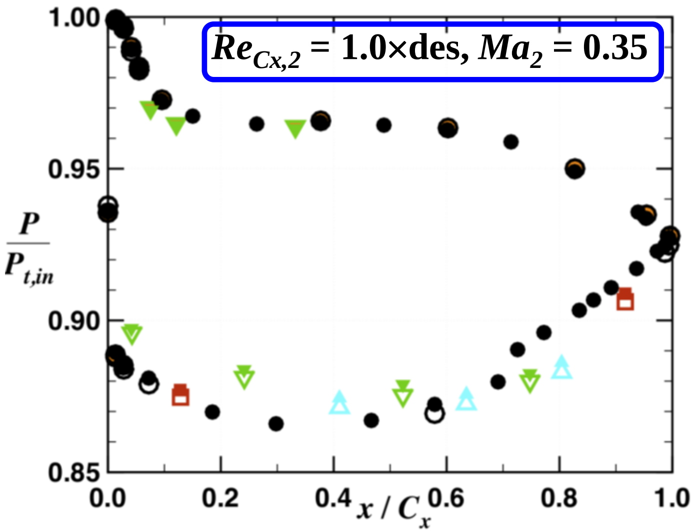
Blade Loadings at β_1=40.0º

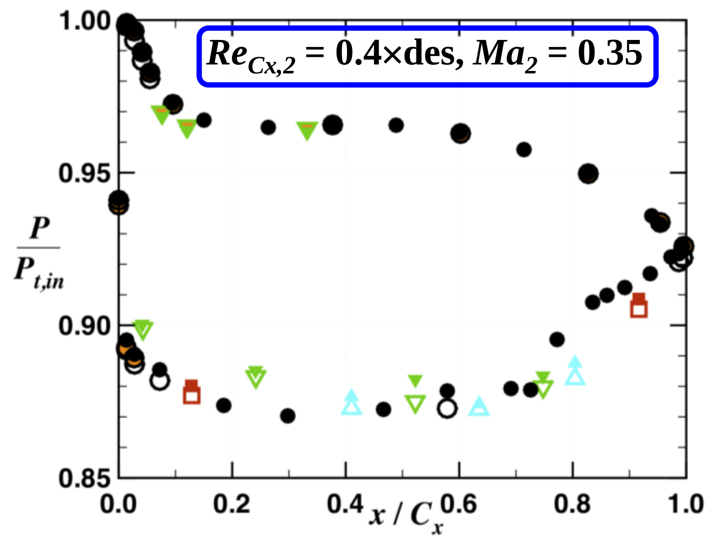
Effects of Reynolds Number and Pressure Ratio at β_1=40.0º (Cruise) i=+5.8º







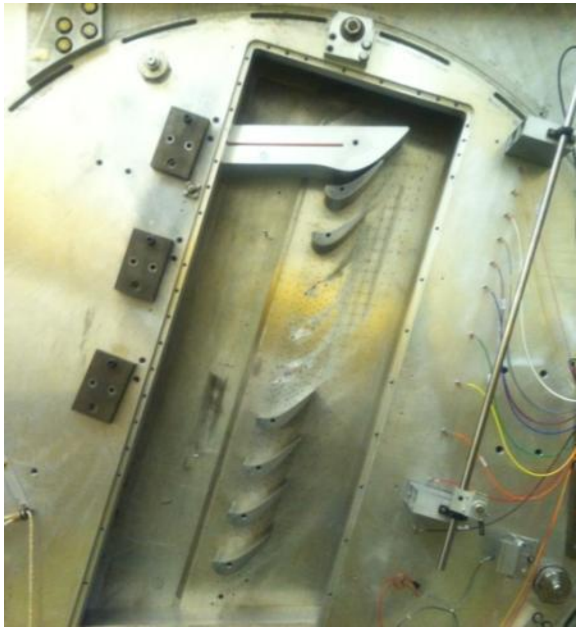




CW-22 Test Configurations

40.0° Inlet Angle
(i = +5.8° Cruise)

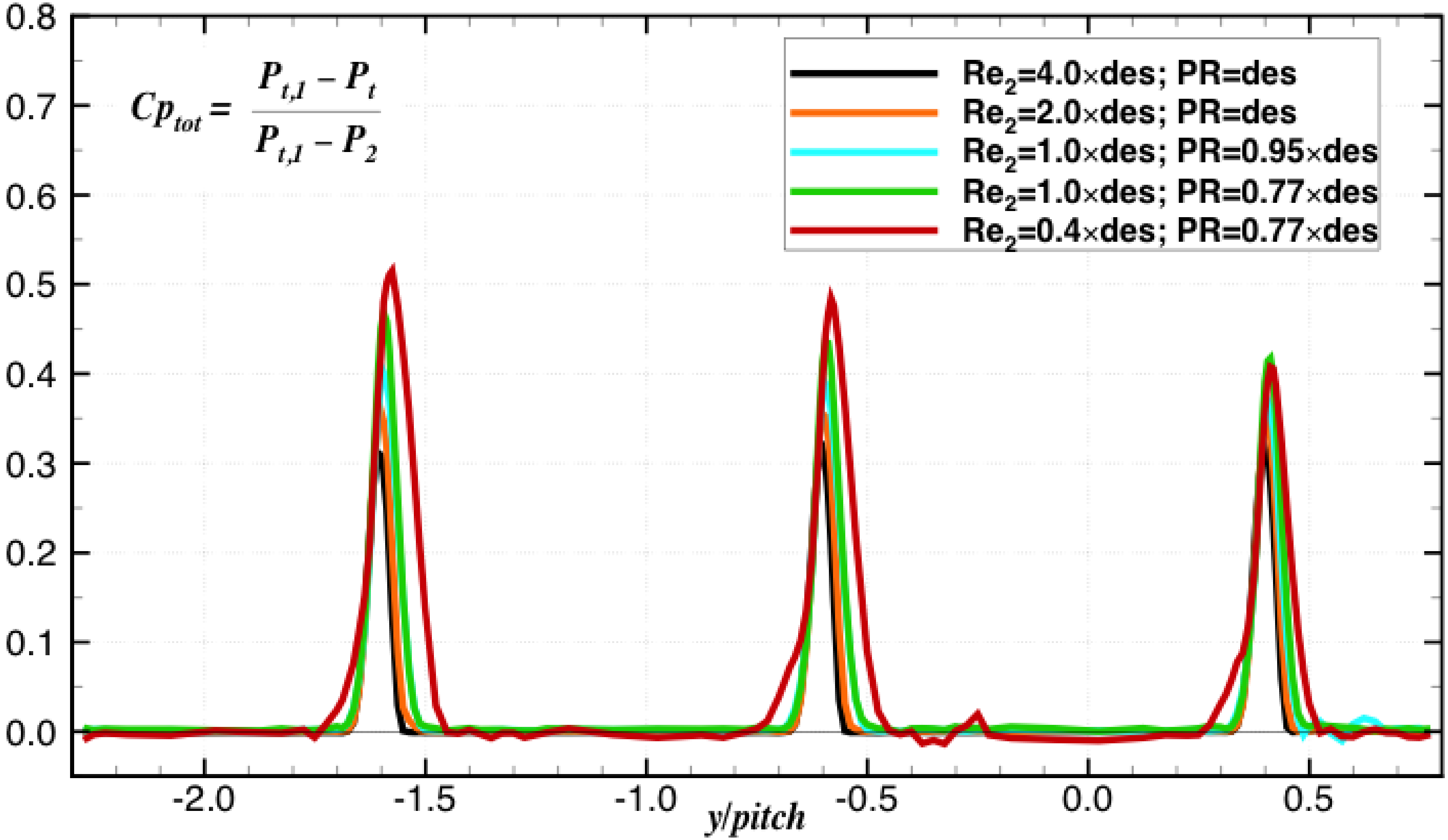
-2.5° Inlet Angle
(i = -36.7° Take-Off)



-11.8° Inlet Angle
(i = -46.0° Maximum Incidence Condition)

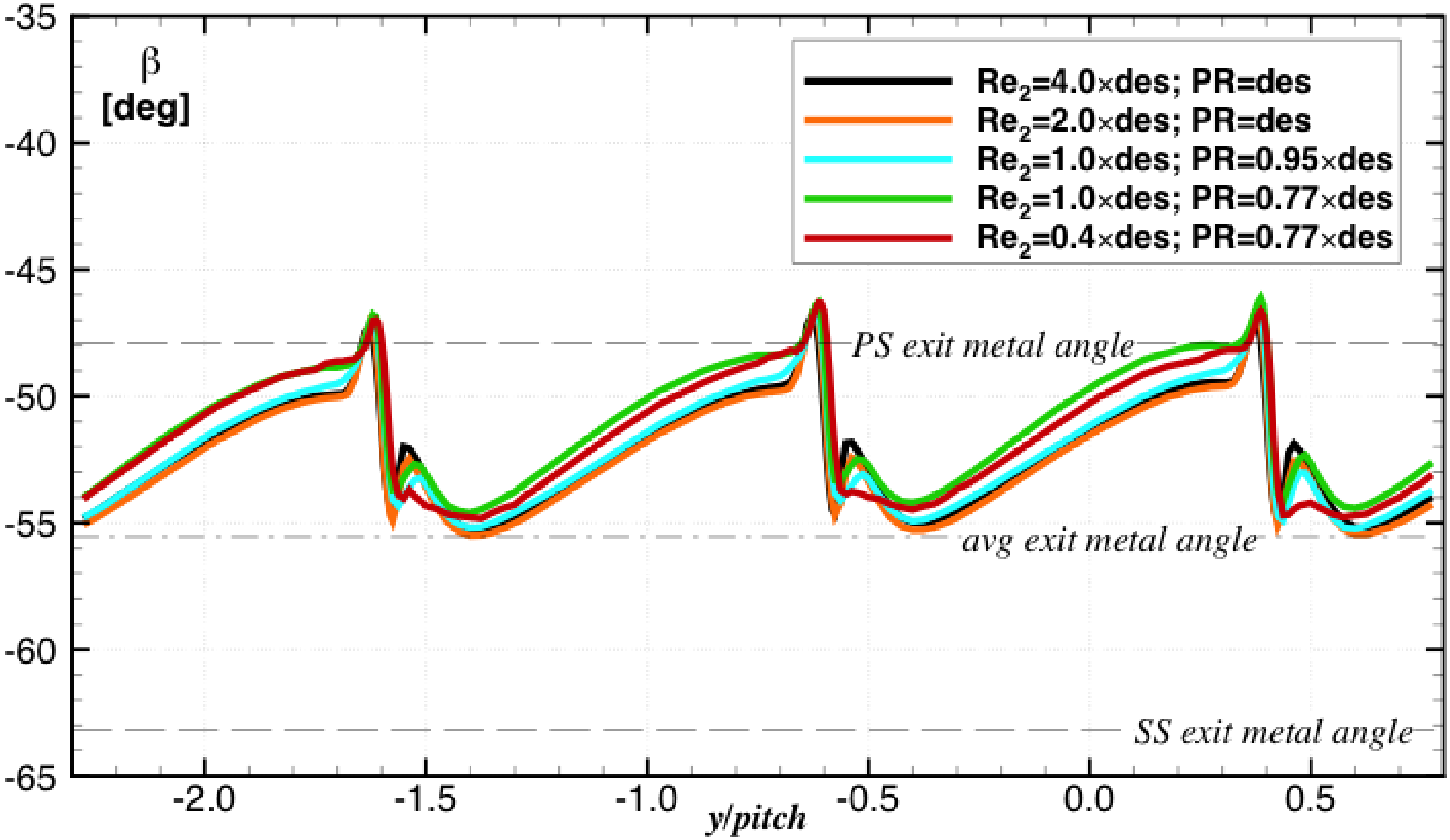
Midspan Probe Loss Measurements

Effects of Reynolds Number and Pressure Ratio at β_1=-2.5º (Take-off) i=-36.7º



Midspan Probe Flow Angle Measurements

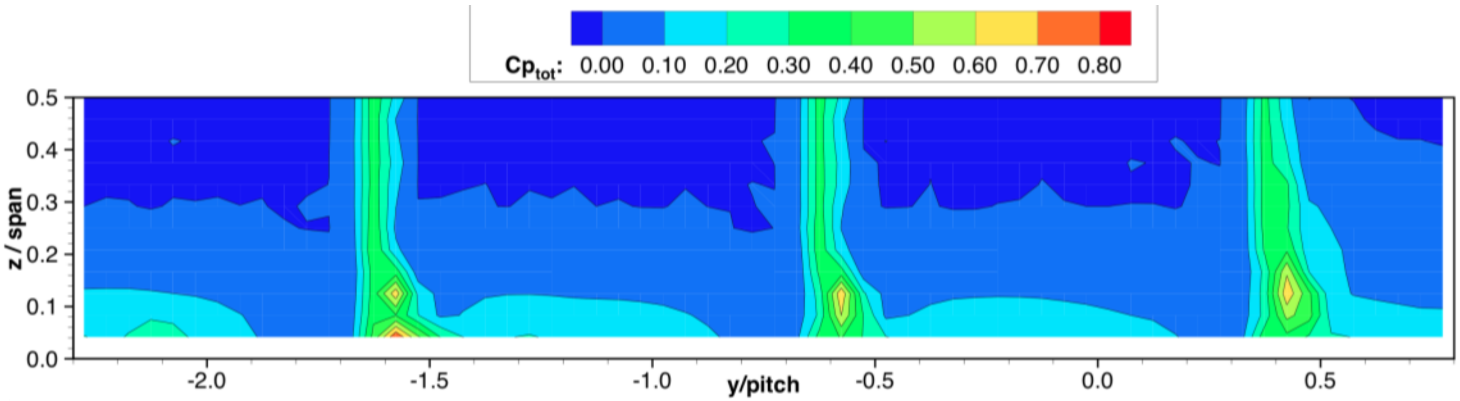
Effects of Reynolds Number and Pressure Ratio on Flow Angle at β_1=-2.5º (Take-off) i=-36.7º



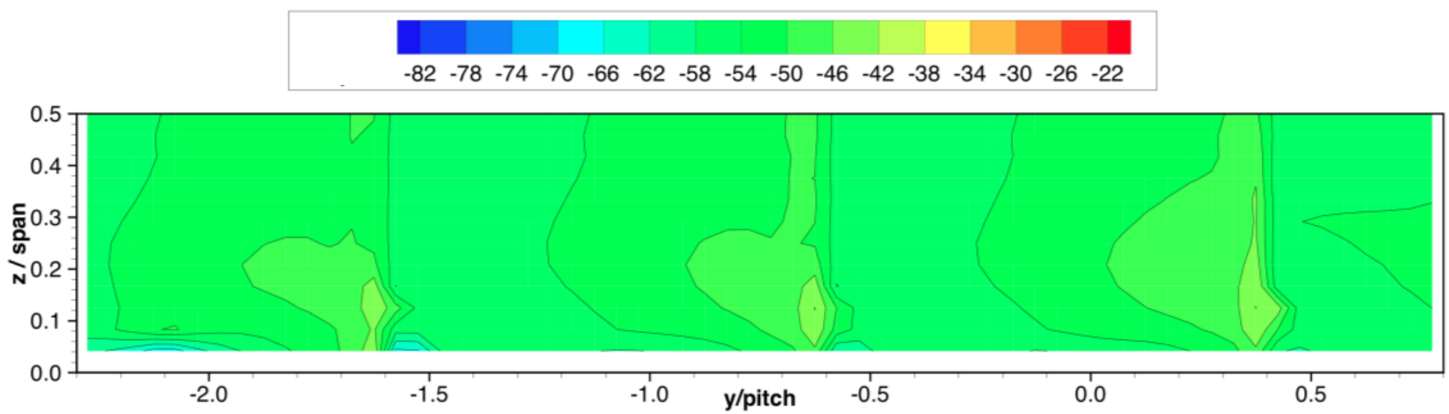
3-D Flowfield Measurements

$Re_{Cx,2}$ = 530,000 (design) Ma_2 = 0.67 (PR=0.95xdes) β_1 = -2.5 (Take-Off) i=-36.7º

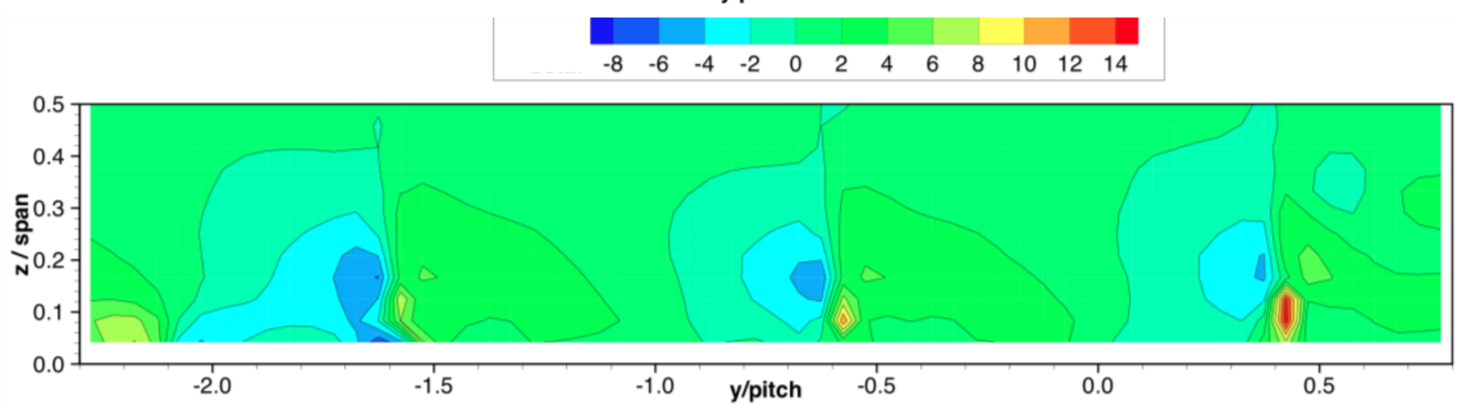
total pressure coefficient



pitch flow angle

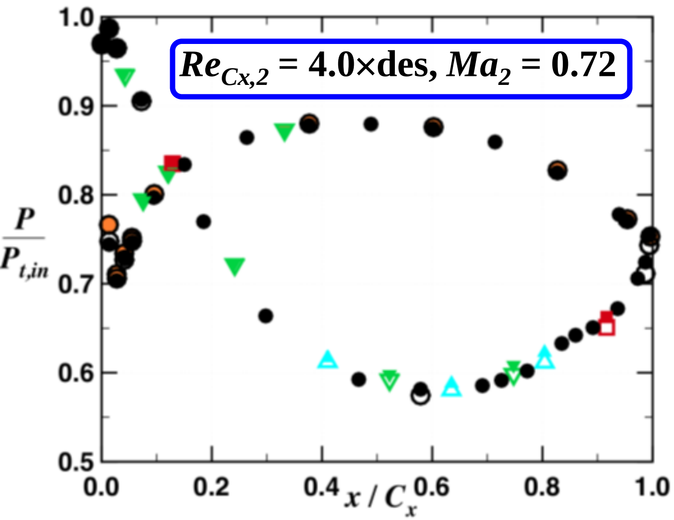


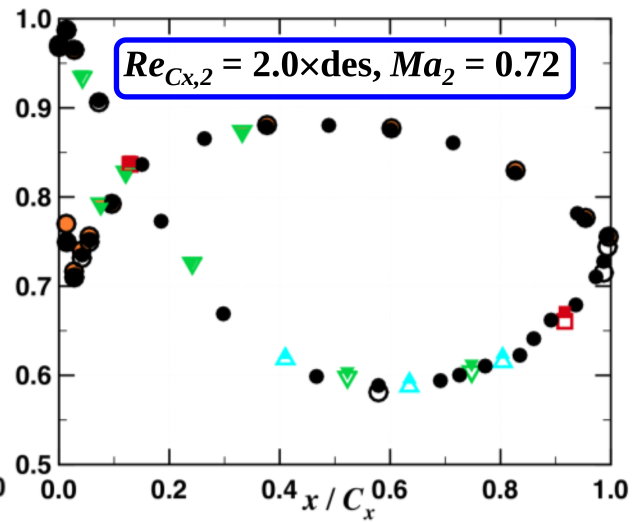
yaw flow angle

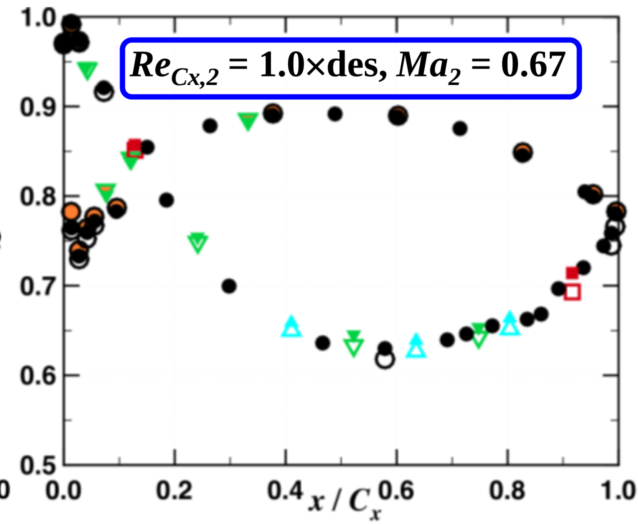


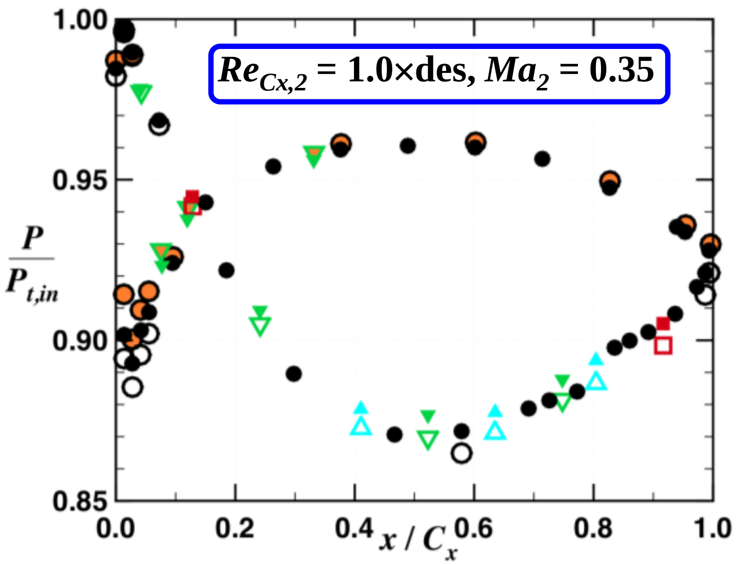
Blade Loadings at β_1 = -2.5º

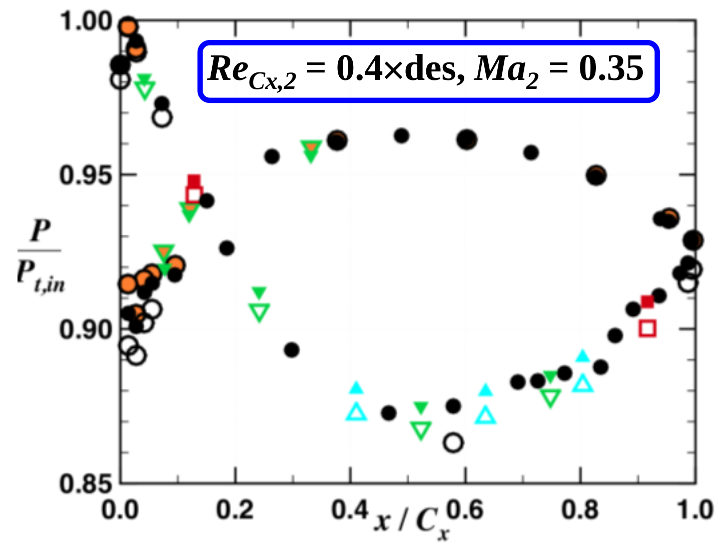
Effects of Reynolds Number and Pressure Ratio at β_1=-2.5º (Take-off) i=-36.7º





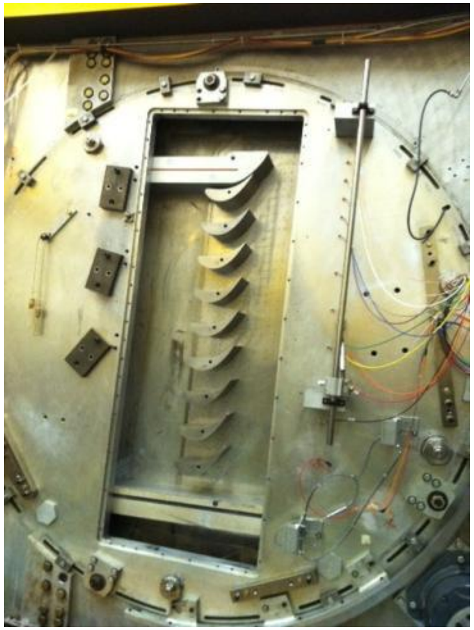






CW-22 Test Configurations

40.0° Inlet Angle
(i = +5.8° Cruise)

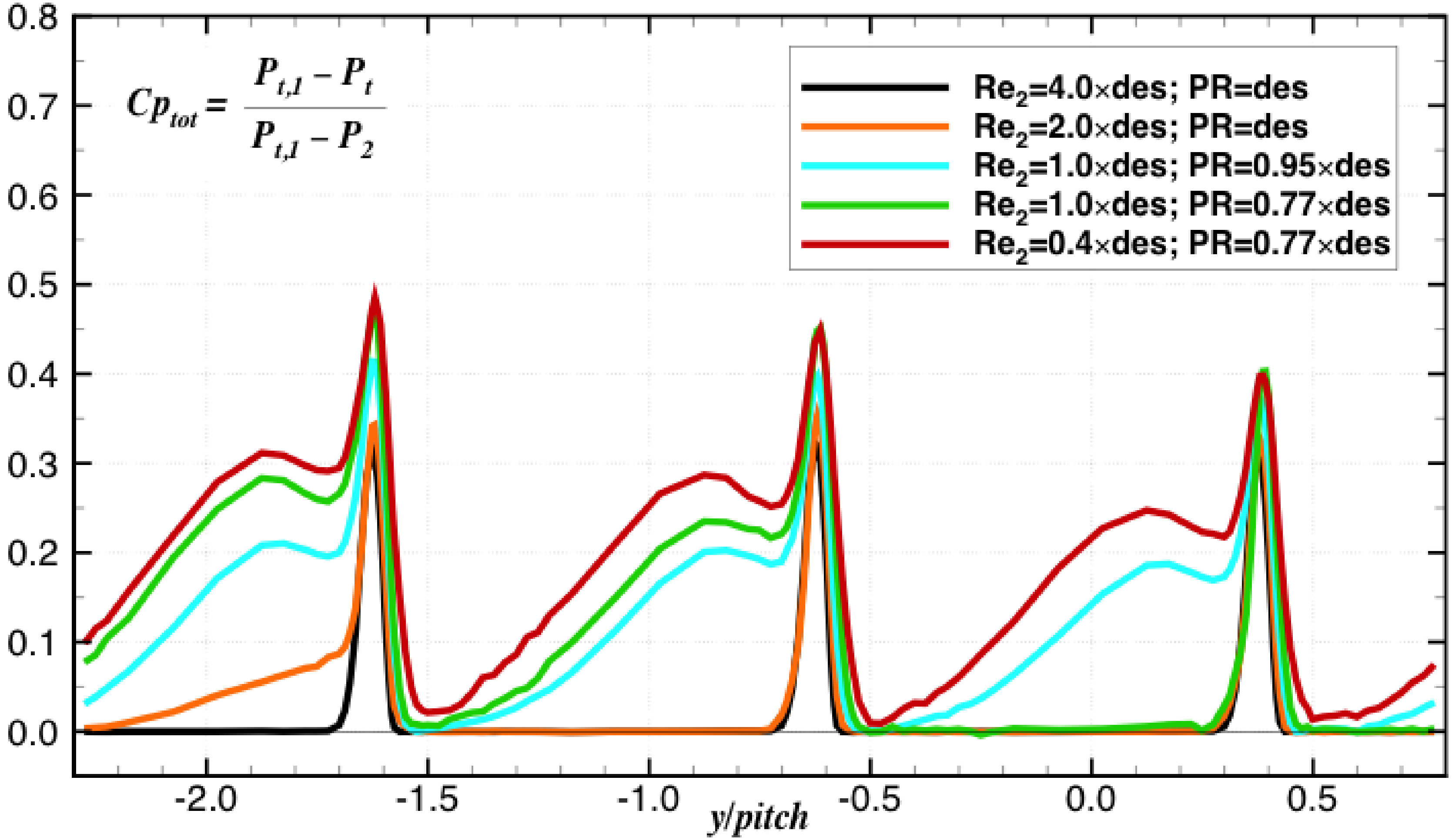


-2.5° Inlet Angle
(i = -36.7° Take-Off)

-11.8° Inlet Angle
(i = -46.0° Maximum Incidence Condition)

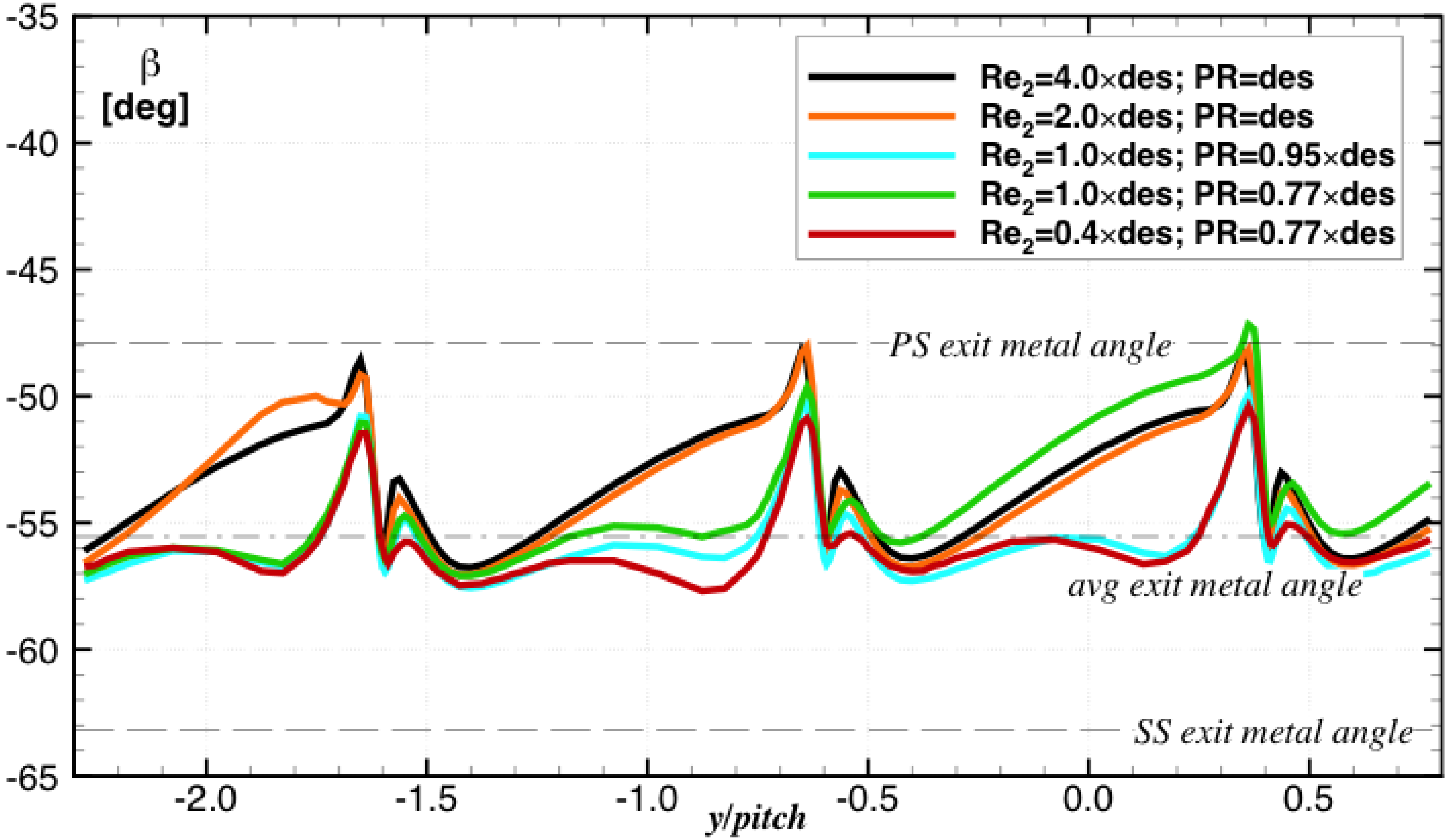
Midspan Probe Loss Measurements

Effects of Reynolds Number and Pressure Ratio at β_1 = -11.8º (i = -46.0º)



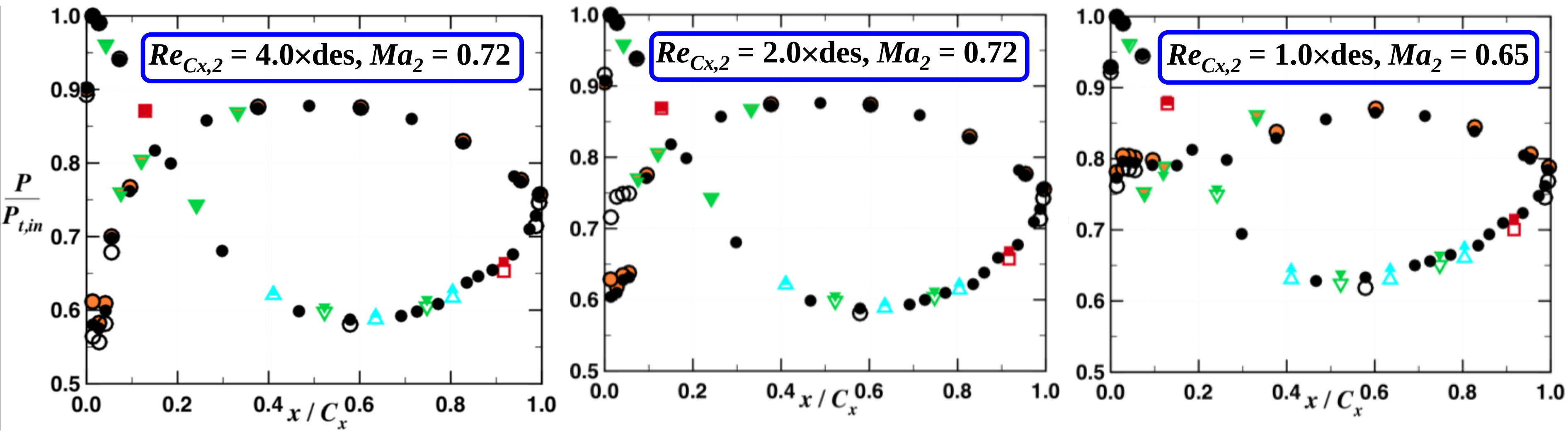
Midspan Probe Flow Angle Measurements

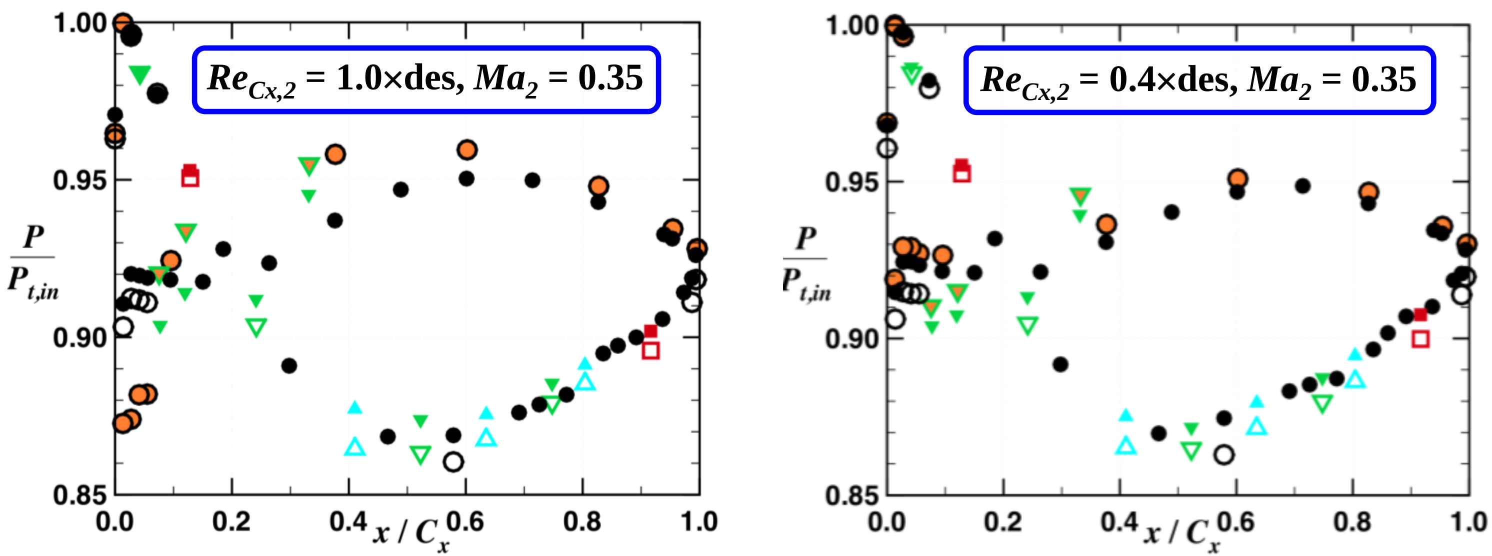
Effect of Reynolds Number and Pressure Ratio on Flow Angle at
β_1 = -11.8˚ (Max Incidence) i = -46.0º



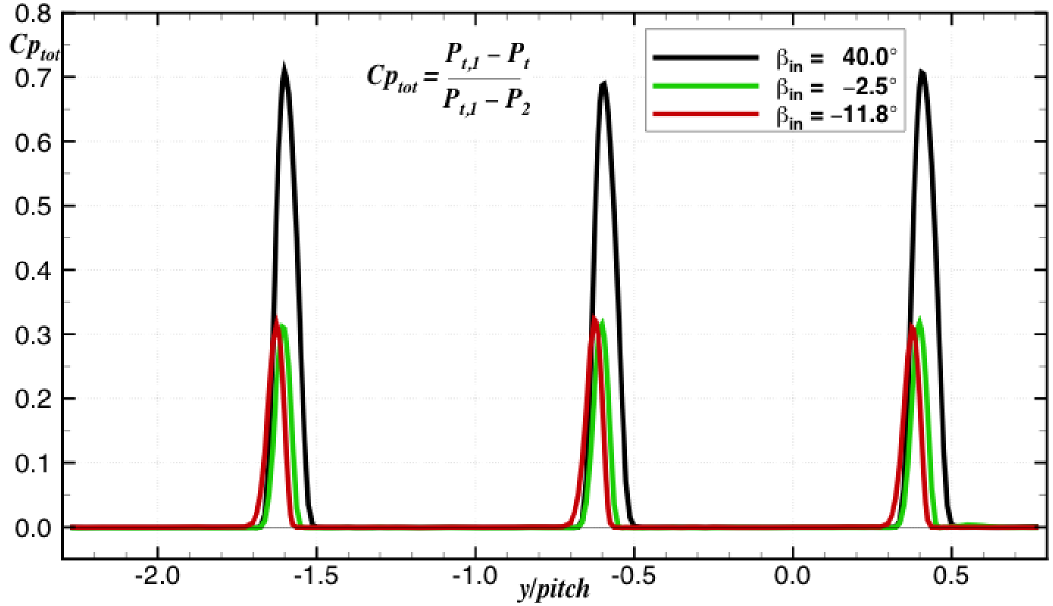
Blade Loadings at β_1=-11.8º

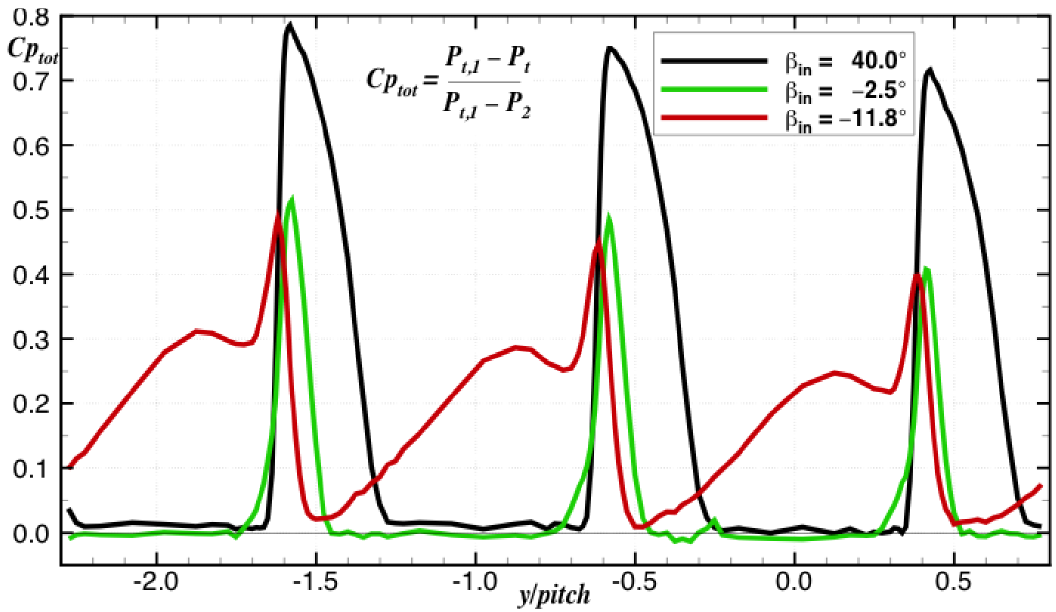
Effects of Reynolds Number and Pressure Ratio at β_1 = -11.8º (i = -46.0º)





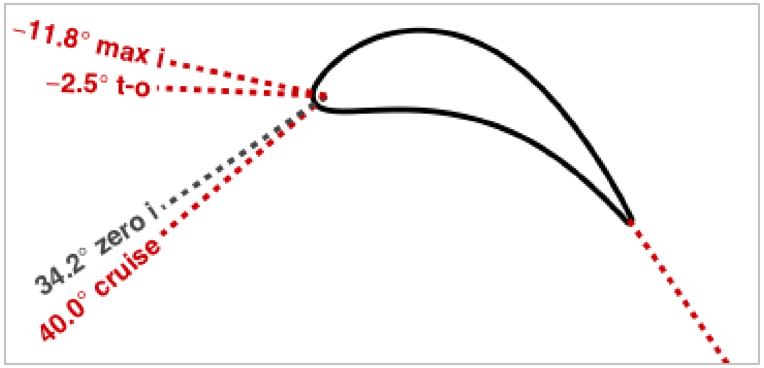
Midspan Probe Loss Measurements





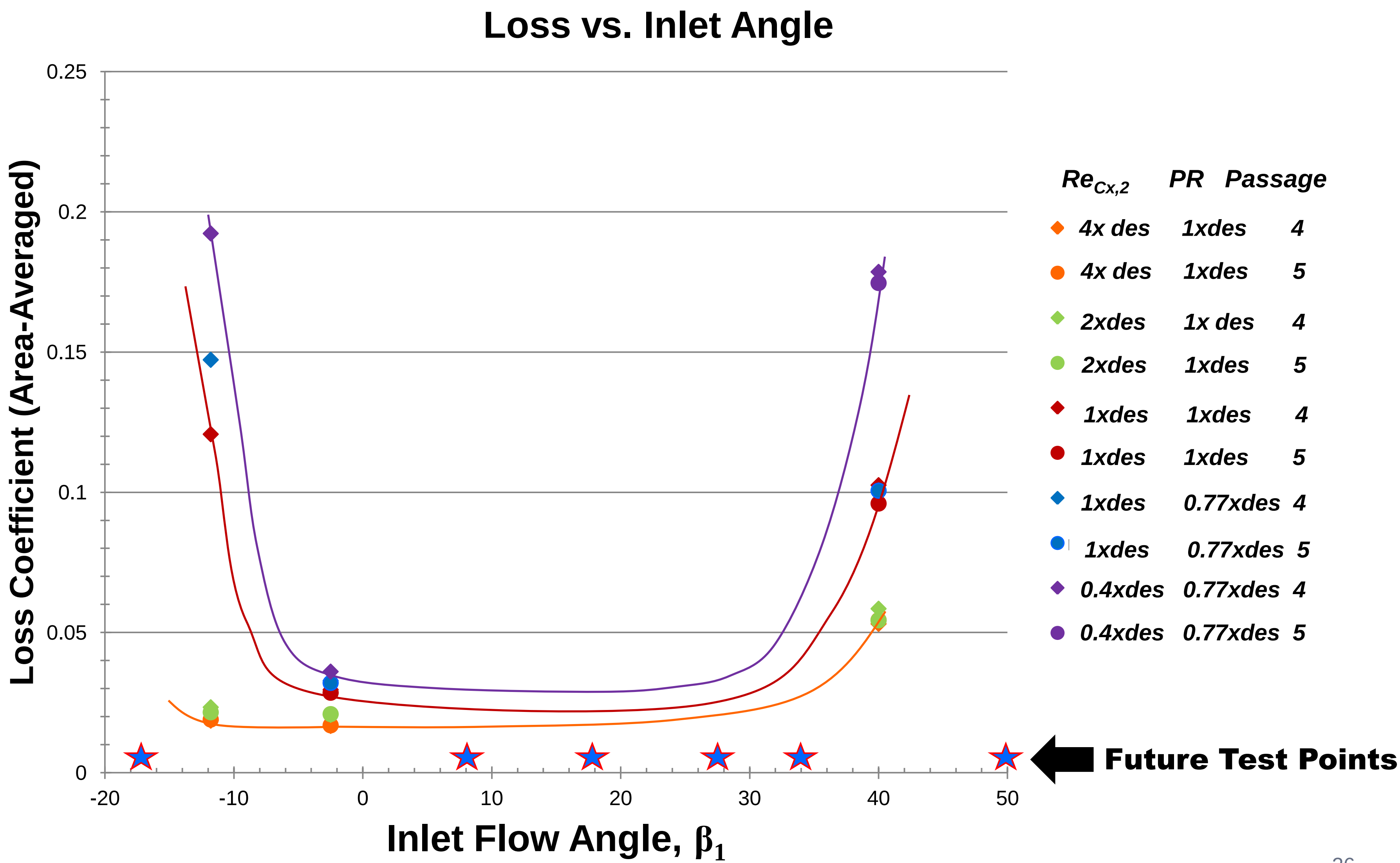
Effects of Inlet flow angle at:

$Re_{cx,2}$=4.0xdesign M_2=0.72
(2.12×10^6)



$Re_{cx,2}$=0.4xdesign M_2=0.35
(0.21×10^6)

Loss Measurements



NASA